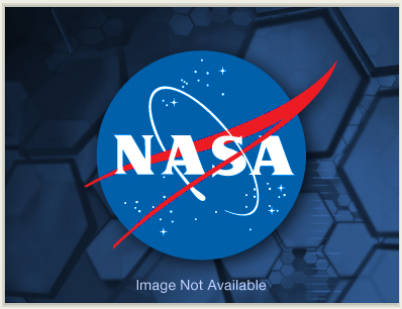
# Computational Technologies: "An Assessment of Hybrid Quantum Annealing Approaches for Inferring and Assimilating Satellite Surface Flux Data into Global Land Surface Models."

Completed Technology Project (2017 - 2019)

## Project Introduction

The objective of this proposal is to expand the research progress the investigators have made in developing Quantum Annealing algorithms that can contribute directly to supporting science related NASA Earth science mission products on the current Ames D-Wave 2X, but to also port and substantially extend these capabilities to the next generation D-Wave 2000Q, when and where available. In particular, having developed unique hybrid neural net algorithmic capabilities for the OCO-2 mission, we plan to expand our research to a broader class of Earth science mission data products and problems, namely calculating surface fluxes from other satellite data products and fusing these data for land surface model data assimilation This includes completing the development, testing and evaluation of Ensemble Quantum Kalman-filter algorithms applicable to current and planned Earth Science missions over the next two years and beyond. We will conduct extensive validation demonstrations of the potential of these D-Wave quantum annealing algorithms at ARC, which we believe will show significant scientific impacts and benefits, potentially more effective than what can be achieved with todays classical computers. It is our, and others, experience that NN optimization algorithms lend themselves especially well to quantum annealing architectures. If successful, this mission enhancing capability would lead to consideration of continued quantum computer technology infusion over the next four years for integration into an operational phase. As use cases, we initially focus on assessing the D-Wave quantum annealing capability to address (i) the Global Carbon Source and Sink budgets over land (ii) perform image registration for direct estimates of Vegetation Growth from Solar Induced Fluorescence employing a multi-satellite Triple Collocation NN quantum algorithm and (iii) conduct Data Information Fusion analysis of Satellite and In-Situ Sensor observations with Reanalysis Model Outputs. We will extend our 3-year OCO-2 data collection to 5-years to infer annual variations in quantum computed global gridded CO2 fluxes, and to the upcoming ISS based OCO- 3 if available in the next two years. We have successfully fitted a highly complex turbulent multivariate, non-linear ARM data set employing a feed forward and backward propagation neural net algorithm on a loosely coupled ARC D-Wave 2X system used as a co-processor accelerator with a remote cluster at UMBC for the general purpose computations. The algorithm performed thousands of samples and hundreds of epochs with two hidden layers. Utilizing these algorithms, we have shown that we can infer CO2 fluxes utilizing historical ARM data for training that is comparable with classic computers. We believe this is the first time one has successfully demonstrated that the D-Wave can perform feed forward regressions yielding comparable results to that obtained with classical computers by employing the D-Wave in such a hybrid algorithmic approach. In this follow-on proposal, we plan to completely couple the hidden layers, forming a Boltzmann Machine, as part of the feed forward algorithm and will test various methods for recalculating the training weights in the backward

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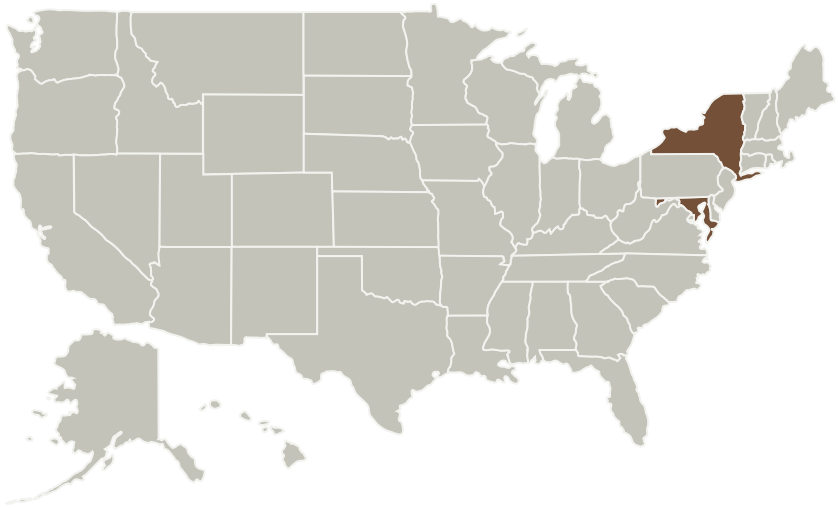
propagation, which should produce improved global optimizations. This could prove to be a unique quantum capability capable of improved global optimization not reasonably possible with conventional computers. We have added several additional Earth scientists to substantially broaden the quantum computational science scope of applications. Thus, if awarded, we expect to improve on the current TRL 3/4 quantum computing capabilities to achieve a TRL 5/6 by the end of the proposed solicitation, thereby moving quantum annealing computing well on its way towards operational infusion.

### Primary U.S. Work Locations and Key Partners



| Organizations Performing Work | Role | Type | Location |
|---|---|---|---|
| University of Maryland-Baltimore County(UMBC) | Lead Organization | Academia<br>Asian American<br>Native American<br>Pacific Islander<br>(AANAPISI) | Baltimore, Maryland |

| Primary U.S. Work Locations | |
|---|---|
| Maryland | New York |

## Organizational Responsibility

**Responsible Mission Directorate:**

Science Mission Directorate (SMD)

**Lead Organization:**

University of Maryland-Baltimore County (UMBC)

**Responsible Program:**

Advanced Information Systems Technology

## Project Management

**Program Director:**

Pamela S Millar

**Program Manager:**

Jacqueline J Le Moigne

**Principal Investigator:**

Milton Halem

**Co-Investigators:**

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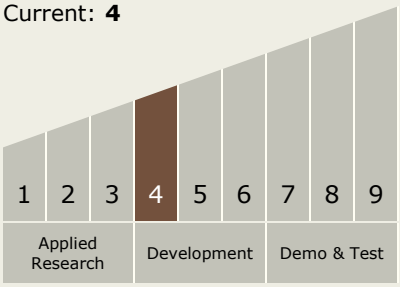
## Technology Maturity (TRL)

Start: **4**
Current: **4**




## Technology Areas

**Primary:**

- TX11 Software, Modeling, Simulation, and Information Processing
  - TX11.6 Ground Computing
    - TX11.6.4 Quantum Computer

## Target Destination

Earth